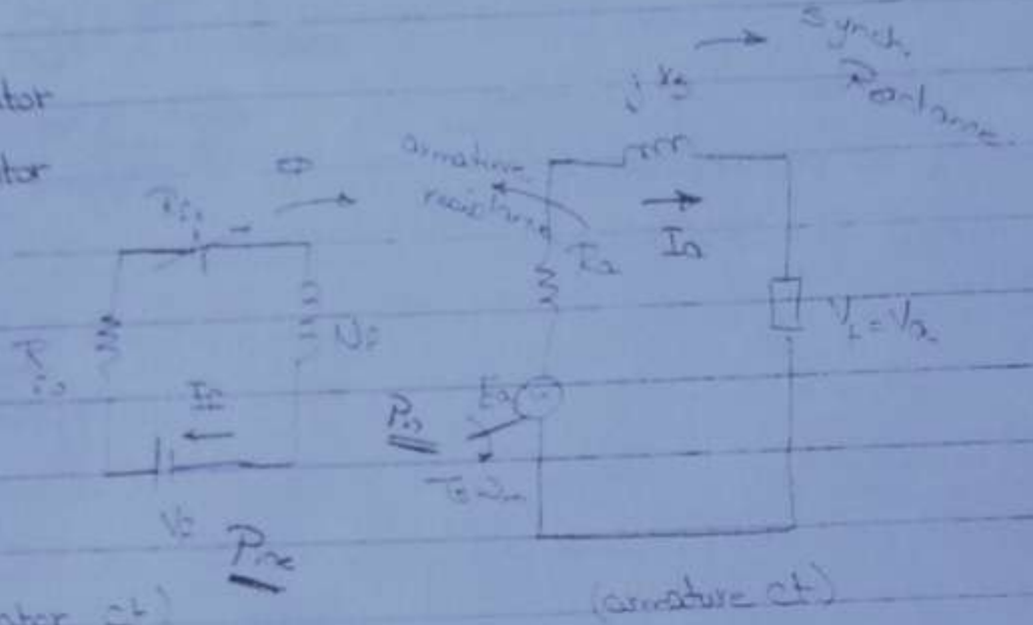
Synchronous Generator

3-ph AC Mach

→ stator

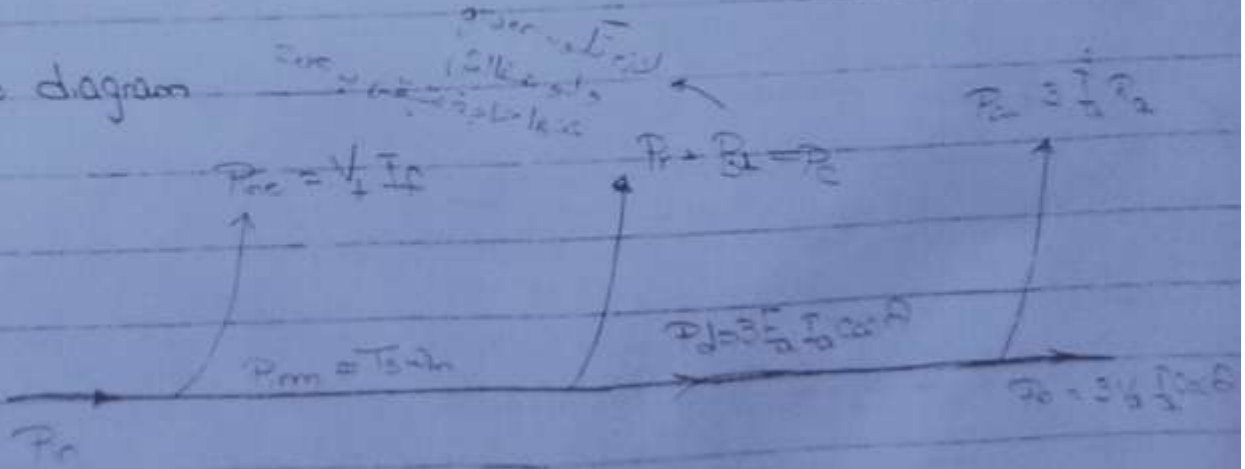
→ rotor



Synch. Reactance
jXs
armature resistance
Ra
Ia
Vt = Va
Ea
Pin
Ts ωm
Rf
Vf
If
Vf
Pin
(stator ct)
(armature ct)

Field ct

power flow diagram



Pout = Vf If
Pr + PL = Pc
Pcu = 3 Ia² Ra
Pin
Pm = Ts ωm
Pd = 3 Ea Ia cos θ
Po = 3 Va Ia cos θ

$$P_{loss} = I_a^2 R_a$$

$$E_a = V_a + I_a (R_a + jX_s)$$

N.B [illegible] power [illegible] AC [illegible] magnitude [illegible]

Ex 2-6

- أي قيمة given في ال Gen. بتعبر ال o/p

$3V_a I_a$

$S = 9\,kVA$, $V_{a_L} = V_t = 208\,V$

- كل الـ given اللي عندي line يبقى انا الملتزم أحوله phase

$$\boxed{V_{ph} = \frac{V_L}{\sqrt{3}}}$$

N.B

For Y connected

$V_{ph} = \frac{V_L}{\sqrt{3}}$ ← given

Δ - connected

$V_{ph} = V_L$

Y - connected

armature wdg resistance ← $R_a = 0.1\,\Omega/\text{phase}$

$X_s = 5.6\,\Omega/\text{phase}$

syn. reactance

Find

① $VR\% = ??$ → p.f
- → 0.8 Lag
- → unity
- → 0.8 Lead

Sol.

magnitude وزاوية

$$VR\% = \frac{E_a - V_t}{V_t}$$

$$E_a = V_t + I_a(R_a + jX_s)$$

$$V_t = V_a = \frac{208}{\sqrt{3}} = 120\,V$$

$$I_a = \frac{S}{3V_a} = \frac{9 \times 10^3}{3 \times 120} = 25\,A$$

ال V_t ثابت الـ E_a هو اللي بيتغير بتغير pf هو اللي هاحسبه في ال ٣ حالات ال p.f

* at 0.8 lag:

عشان Lag

$I_a = 25\angle{-36.87^\circ}$

N.B

p.F → $\hat{V_a}\ \hat{I_a}$

cos $\hat{V_a} - \hat{I_a}$

$E_a = 120 + 25\angle{-36.87}\ (0.1 + 5.6j)$

$= 233.87\angle{28.21^\circ}\ V$

ماخد mag. بس

$V.R\% = \frac{233.87 - 120}{120} * 100 = 94.8\%$

* at unity:

p.F = unity

$\cos^{-1} 1 = 0$

$I_a = 25\angle{0^\circ}\ A$

$E_a = 120 + 25\angle{0^\circ}\ (0.1 + j5.6)$

$= 186.03\angle{48.8^\circ}$

$VR\% = \frac{186.03 - 120}{120} * 100 = 55.03\%$

* at 0.8 Lead.

$I_a = 25\angle{36.87}$

$E_a = 120 + 25\angle{36.87}\ (0.1 + j5.6)$

$= 119.69\angle{71.5^\circ}\ V$

$V.R\% = \frac{119.69 - 120}{120} = -0.26\%$

N.B دايماً فى ال lag وال unity ال VR% بيبقى +ve
وال Lead +ve

Sketch phasor Diagram

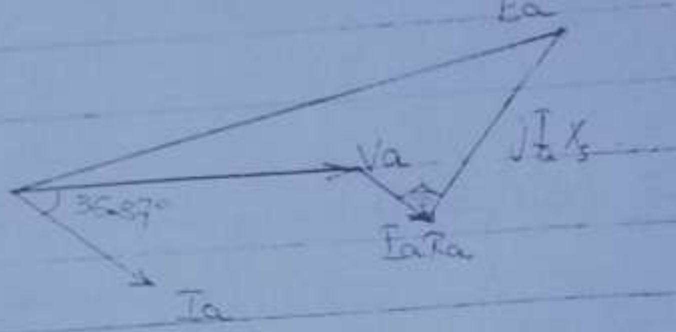
At 0.8 Lag.

$$E_a = V_a + I_a(R_a + jX_s)$$
$$= V_a + \boxed{I_a R_a} + jI_a X_s$$

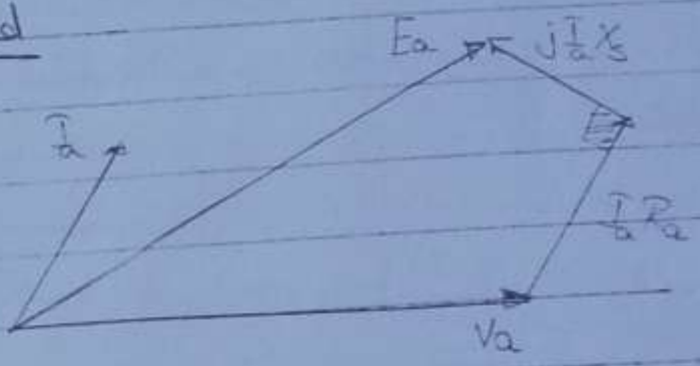
دي كدة volt بس بنفس زاوية I_a

عشان Ra ملهاش زاوية

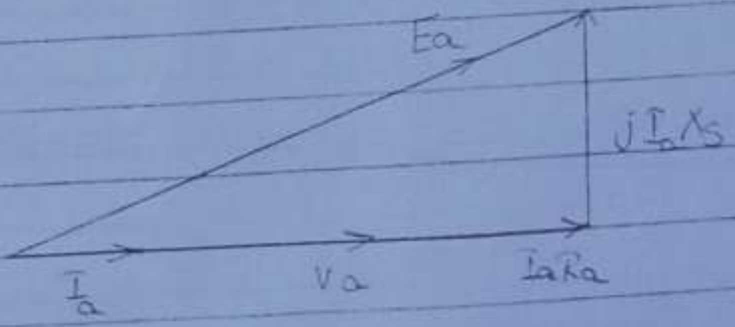
N.B. scale مش مهم


Ea
Va
jI_aX_s
36.87°
I_aR_a
Ia

At 0.8 Lead


Ea
jI_aX_s
I_a
I_aR_a
Va

At unity


Ea
jI_aX_s
I_a
Va
I_aR_a

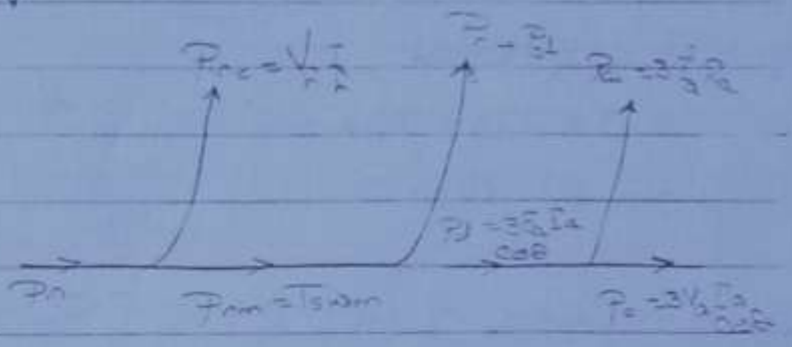
N.B.: في ال unity ال I_a برسمه ع ال V_a

Ex 2.7

$S = 9kVA \quad , V_a = V_t = 208V$

$N_m = 1200$ rpm

$R_f = 4.5\,\Omega$


$P_{rc} = V_r I_r$
$P_r + P_l$
$P_{cu} = 3 I_a^2 R_a$
$P_d = 3 E_a I_a \cos\delta$
P_{in}
$P_{cm} = T_s \omega_m$
$P_o = 3 V_a I_a \cos\theta$

$Z_a = R_a + jX_s$

$= 0.3 + j5$

$\rightarrow$ 0.8 p.f Lag

-f = 5A

$P_r = 500$ ω

det..

① V.R %

② η

③ T_s

Sol.

$$E_a = V_t + I_a(\overset{0.3+5j}{R_a + jX_s})$$

$$V_t = \frac{208}{\sqrt{3}} = 120V$$

$$I_a = \frac{S}{3V_a} = \frac{9 \times 10^3}{3 \times 120} = 25\angle{-36.87^\circ}\ A$$

$$E_a = 120 + 25\angle{-36.87^\circ}\ (0.3 + j0.5)$$
$$= 222.3\angle{25.4^\circ}\ V$$

$$V.R\% = \frac{222.3 - 120}{120} = 85.2\%$$

magnitude only

$$P_o = 3\, V_a \overset{\uparrow}{I_a} \cos\theta$$

$$= 3 * 120 * 25 * 0.8$$

$$= 7200\ \text{w}$$

$$P_{ine} = I_f V_f = I_f\,(I_f R_f) = I_f^2 R_f$$

$$= 5^2 * 4.5 = 112.5\ \text{w}$$

$$P_{inm} = P_d + P_r$$

$$P_d = 3 E_a I_a \cos\theta = 3 * 222.3 * 25 * 0.8$$

$$= 13.3\ \text{kw}$$

$$P_{inm} = \overset{500}{P_r} + P_d$$

$$= 500 + 13.3 * 10^3$$

$$= 13.8\ \text{kw}$$

$$T_s = \frac{P_{inm}}{\omega_m} \quad \omega_m \rightarrow \frac{2\pi N_m}{60}$$

$$T_s = ✓$$

$$P_{in} = P_{inm} + P_{ine} = ✓\ \text{w}$$

$$\eta = \frac{P_o}{P_{in}}$$

3ph. I.M

→ stator $\phi_1 \rightarrow N_s = \frac{120f}{P}$

→ Rotor $\phi_2 \rightarrow N_r$

لو مجالين متعاكسين
تتلاشى

I.M

$N_s \neq N_r$ $N_s > N_r$

$(\text{slip})\ (s) = \frac{N_s - N_r}{N_s} = \text{--}$ p.u ← per unit

rotor ct ← $F_r = sF$ → frequency of stator

+ at starting:-

$N_r = 0$

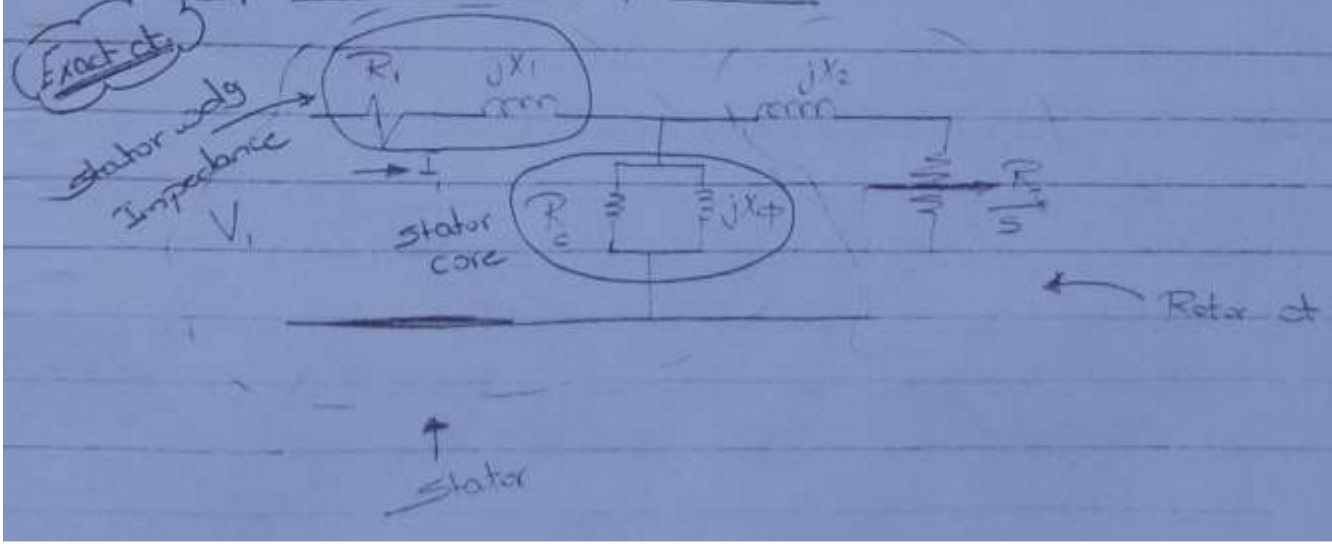
$s = 1$ p.u

+ at Running-

$S \le 0.05$ p.u ال Nr هتزيد و S هتقل

Equivalent ct of 3ph. I.M.

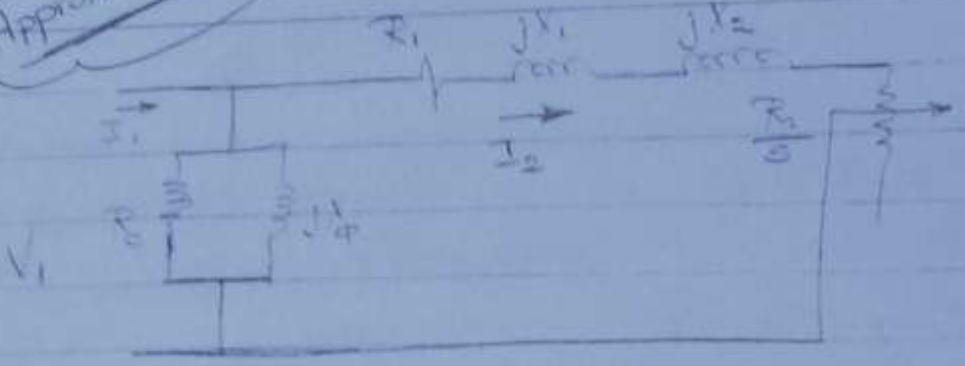
Exact ct.



R_1
jX_1
jX_2
stator wdg Impedance
I_1
V_1
stator core
R_c
jX_m
$\frac{R_2}{s}$
Rotor ct
stator

ص

Approximate equiv. ct



power flow diagram:

$$P_{in} = 3 V_1 I_1 \cos\theta$$

stator copper loss

stator Loss

$P_{scl} = 3 I_1^2 R$

core loss $= 3 I_c^2 R_c$

air gap Power $= P_{ag}$

$T_d \omega_s$

الـ loss هتبقى في $\frac{R_2}{S}$ مش في الـ ...

$$P_{ag} = 3 I_2^2 \boxed{\frac{R_2}{S}}$$

$R_m = \frac{R_2}{S}(1-S)$ $\qquad R_2$

عندى مقاومتين يبقى عندى power

$P_{rcL} = 3 I_2^2 R_2$

rotor copper loss

$P_m = 3 I_2^2 R_m$

$P_r = P_f + w$

قوه الرياح

$P_o = T \omega_m$

لو طلب الـ (η) eff. لازم أرسم الرسمة

[illegible] connected
Y connected

3 ph I.M, 433V (line) runs at speed of 1425 rpm, 4-pole, 50HZ, has the following parameter:- Y-connected

$R_1 = 0.1\Omega$, $X_1 = 0.3\Omega$

$R_2 = 0.115\Omega$, $X_2 = 0.4\Omega$

$R_c = 125\Omega$, $X_\phi = 50\Omega$

$P_r = 2300\ W$

Determine:- ① i/p current , i/p powerfactor

② η

Sol.

$N_r = 1425$ rpm

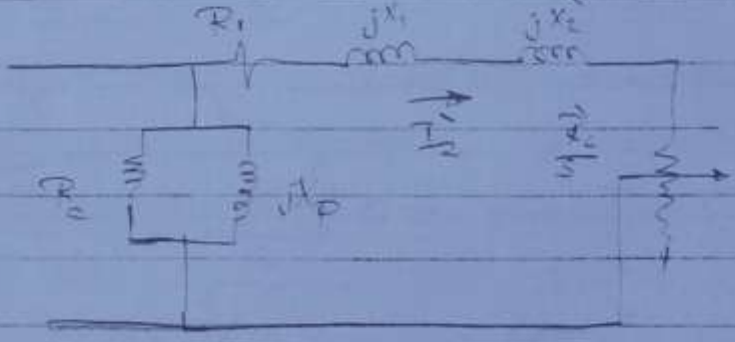
$N_s = \frac{120f}{P} = 15$

ع.لا لو مدينيش الـ P هنفرضه من عندي بشرط انه يكون الفرق بينها وبين الـ Nr مش كبير.

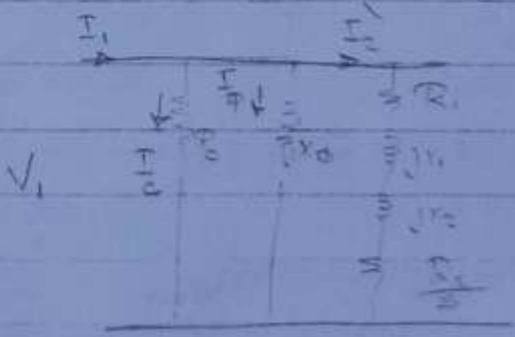
Sol.

$I_1 = I_c + I_\phi + I_2'$

$= \frac{V_1}{R_c} + \frac{V_1}{jX_\phi} + \frac{V_1}{(R + \frac{R_2}{s}) + j(X_1 + X_2)}$



R_1
jX_1
jX_2'
I_2'
R_c
jX_ϕ



I_1
I_2'
I_ϕ
I_c
R_c
jX_ϕ
V_1
R_1
jX_1
jX_2
$\frac{R_2}{s}$

$S = \frac{N_s - N_r}{N_s}$

$= \frac{1500 - 1425}{1500}$

$= 0.05$ p.u

$= 5\%$

$$I_1 = \frac{433/\sqrt{3}}{125} + \frac{433/\sqrt{3}}{50\angle 90^\circ} + \frac{433/\sqrt{3}}{\left(0.1 + \frac{0.115}{0.05}\right) + j(0.3+0.4)}$$

$$= 103.4 \angle -18.6^\circ \ A$$

$$p.F)_i = \cos(\underset{\hookrightarrow 0}{\hat{V}_1} - \hat{I}_1)$$

$$= 0.95$$

$$P_{in} = 3 * \overset{\text{magnitude only}}{V_1} I_1 \cos\theta$$

$$= 3 * \frac{433}{\sqrt{2}} * 0.95 = 73672.5 \ \omega$$

$$P_o = P_m - (\overset{2300}{P_f} + \omega)$$

$$P_m = 3 I_2^2 \frac{\overset{0.115}{R_2}}{\underset{0.05}{S}} (1 - \overset{0.05}{S})$$

Note

$P_m = T_d \omega_m$

$*$ air gap $= T_d \omega_s$

$P_o = T_s \omega_m \rightarrow \omega_r$

$*$ Determine $T_d)_{start}$.

$$P_{ag} = T_d \omega_s = 3 I_2'^2 \frac{R_2'}{S}$$

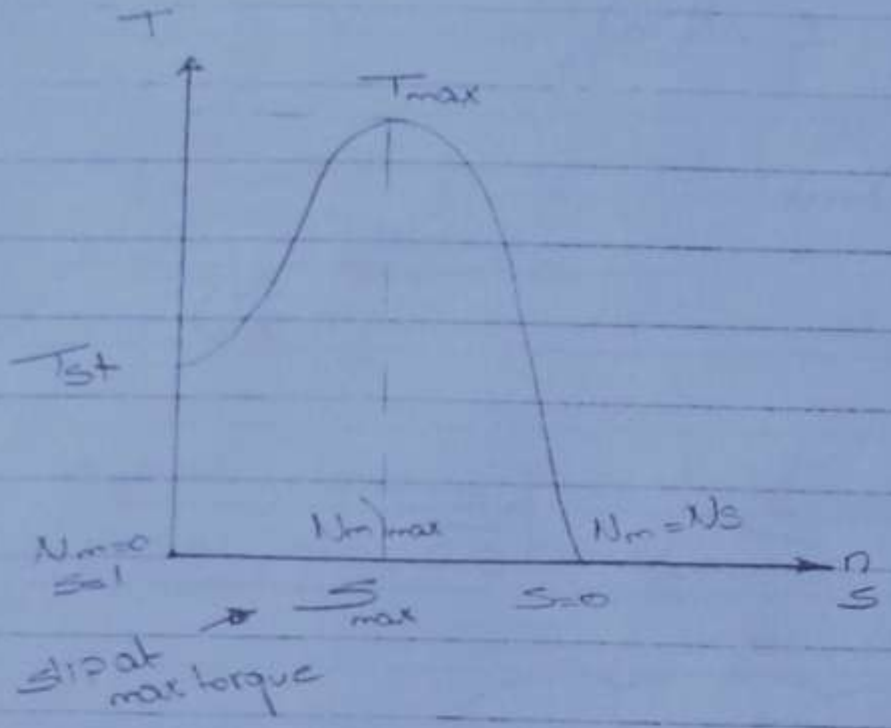
$$T_d)_{start} = \frac{3}{\omega_s} I_2'^2 \frac{R_2'}{S}$$

$$S = 1 \ p.u$$

$$T_d)_{start} = \frac{3}{\omega_s} I_2'^2 R_2'$$

$$I'_2)_{start} = \frac{433/\sqrt{3}}{(0.1+0.115)+j(0.3+0.4)}$$

KLoss's formula



$R_1=0$

$X_r=0$

$$\boxed{\frac{T}{T_{max}} = \frac{2}{\frac{S_m}{S}+\frac{S}{S_m}}}$$

تتبع ال T

V.V.I.P

Ex #2

50HZ , 6 pole

$T_{max} = 150$ N.m

$S_{max} = 20\% = 0.2$ p.u

$T_{FL} = 60$ N.m

Obtain:

① $T_{st} \nearrow$ N.m ; $\searrow$ p.u

② S_{FL} & $N_m)_{FL}$

③ $N_m)_{max}$

$N_s =$

Sol

$$\frac{T_{st}}{150} = \frac{2}{0.2 + \frac{1}{0.2}} = \frac{2}{5.2}$$

T_{st} يتبع T_{max} في الوحدة

$$\boxed{T_{st} = 57.6 \text{ N.m}}$$

$$T_{st})_{p.u} = \frac{T_{st})_{actual}}{T_{FL}} = \frac{57.6}{60} = 0.95 \text{ p.u}$$

لو T_{FL} مش given وادانى $P_o = 50HP$

1 hp → 746 ω

50 → ?? $P_o = 746*50$ watt

$$T)_{p.u} = \frac{T\,(\text{actual}) \leftarrow \text{N.m}}{T_{F.L} \leftarrow \text{N.m}}$$

N.B

S عكس N

$$P_m = P_d = P_o + P_r \xrightarrow{\quad} T_d)_{FL} = \frac{P_m)_{FL}}{\omega_m}$$

$$\frac{T_{FL}}{T_{max}} = \frac{2}{\frac{S_m \to 0.2}{S_{FL}} + \frac{S_{FL}}{S_m \to 0.2}}$$

$S_{FL} = 0.041$ p.u
$= 0.95$ p.u

قيمتين عشان
معادلة تربيعية
هاخد اللي اقل من S_{max}

$$\boxed{S_{FL} = 0.041 \text{ p.u}}$$

$$S = \frac{N_s - N_m}{N_r}$$

$$S N_r = N_s - N_m$$

$$\boxed{N_m = (1 - S)\, N_s} \qquad N_s \leftarrow \frac{120f}{P}$$

S تتبع Nm

$$N_m)_{FL} = (1 - 0.04) * 1000 = 960 \text{ rpm}$$

$$N_m)_{max} = (1 - S_{max})\, N_s = (1 - 0.2) * 1000 \sim 800 \text{ rpm}$$

$T_{FL} = 60 \text{ N.m}$

$$T)_{p.u} = \frac{T)_{N.m}}{T_{FL})_{N.m}}$$

$P_o = 50\text{Hp}$

$$P_m = P_o + \underset{\hookrightarrow 0}{P_r} + \omega$$

$$P_m = T_d\, \omega_m$$

$$T_d)_{FL} = \frac{P_m = P_o \times 746}{\omega_m \rightarrow \frac{2\pi N_m}{60}}$$

Ex

50Hp, $V)_L = 440\text{V}$

4- pole, 60HZ

$N_m)_{FL} = 1746 \text{ rpm}$

$T_{max} = 200\% = 2 \text{ p.u}$

$R_1 = P_r = 0$

Calculate..

① $S)_{max}$, $N)_{max}$

② $T_{st} \rightarrow \text{N.m}$

Sol.

$$\frac{T}{T_{max}} = \frac{2}{\frac{S_m}{S} + \frac{S}{S_m}}$$

$$T_{FL})_{p.u} = \frac{T_{FL})_{N.m}}{T_{FL})_{N.m}} = 1 \text{ p.u}$$

$$\frac{T_{FL}}{T_{max}} = \frac{2}{\frac{S_m}{S_{FL}} + \frac{S_{FL}}{S_m}}$$

$$\frac{1}{2} = \frac{2}{\frac{S_m}{0.03} + \frac{0.03}{S_m}}$$

$$S_{FL} = \frac{N_s - N_m}{N_s}$$

$$= \frac{1800 - 1746}{1800}$$

$$= 0.03 \text{ p.u}$$

$$S_{m_1} = 0.112 \text{ p.u}$$

$$\frac{S_m}{0.03} + \frac{0.03}{S_m} = 4 S_m$$

$$S_m^2 + 0.0009 = 0.12 S_m$$

S_{FL} اكبر $\leftarrow S_{m_1} = 0.112$ p.u

$$S_{m_2} = 8 * 10^{-3}$$

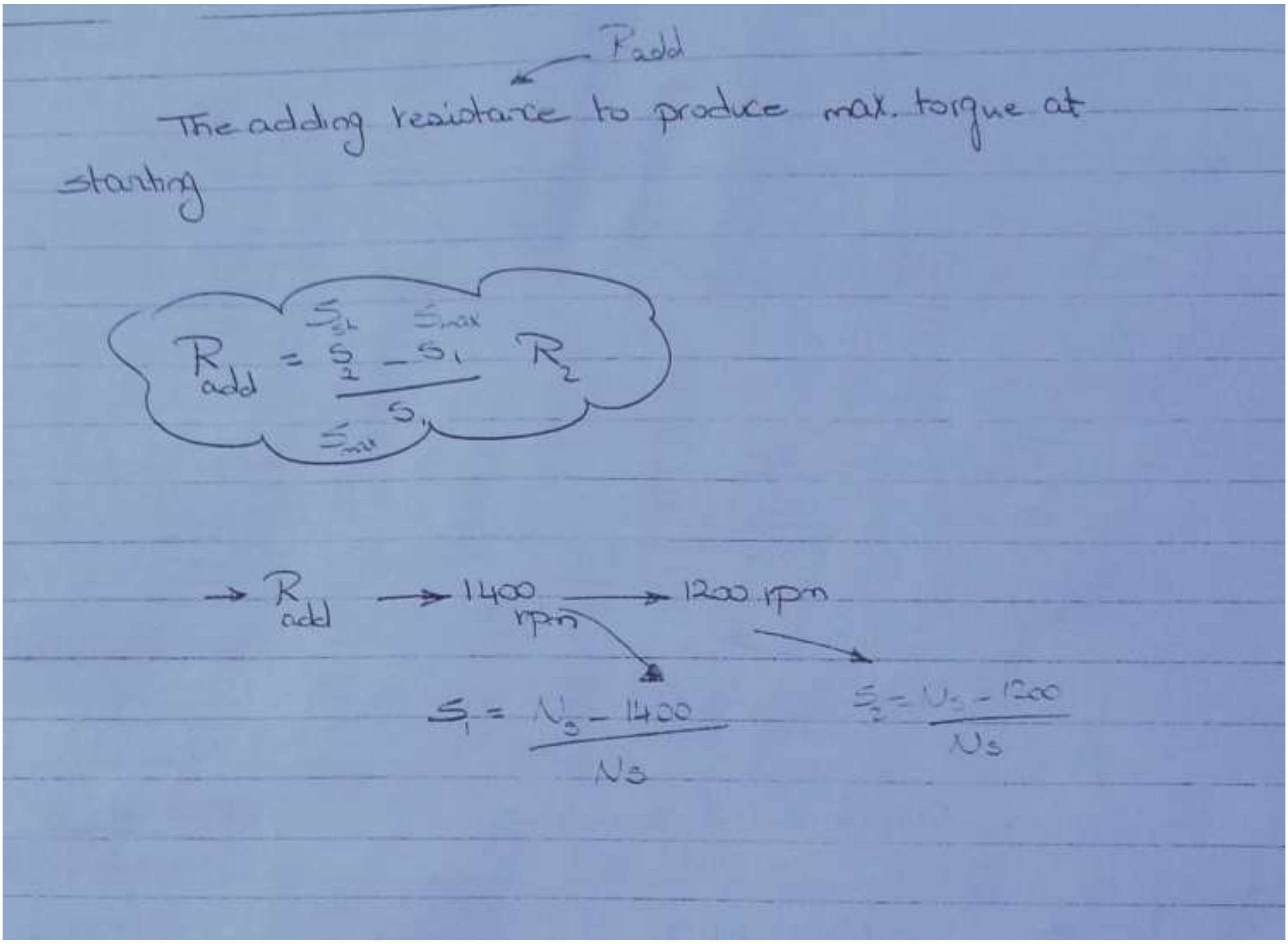
$$N_m)_{max} = (1 - S) N_s$$

$$= (1 - 0.112) * 1800$$

$$= /$$

$$T_{FL})_{N.m} = \frac{\overset{\rightarrow P_o}{P_m}}{\frac{2\pi N_m}{60}}$$

$$T_{st} = \frac{2}{\underset{0.112 \swarrow}{\frac{S_m}{1}} + \frac{1}{0.112}}$$



R_{add}

The adding resistance to produce max. torque at starting

$$R_{add} = \frac{\overset{S_{st}}{S_2} - \overset{S_{max}}{S_1}}{\underset{S_{max}}{S_1}} R_2$$

$$\rightarrow R_{add} \longrightarrow \underset{rpm}{1400} \longrightarrow 1200\ rpm$$

$$S_1 = \frac{N_s - 1400}{N_s} \qquad S_2 = \frac{N_s - 1200}{N_s}$$

http://www.com-dep.tk